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IMPORTANCE AND PROGRESS OF WIND POWER UTILIZATION IN DENMARK /390*

Dimitry Stein

After having reported in the last two numbers on the importance of wind power utilization in the total Danish power economy and on various wind power systems that have been worked out, we shall, in the following, cover operating experience and report some figures on efficiency.

Operating Experience

Aside from the personal experiences of the plant managers of Danish wind power plants, the wind electricity statistics published in the monthly reports of the Union of Directors of National Electricity Plants in Denmark give a survey of the operating results of wind power plants. By November, 1941, these statistics already included the generation data for 64 wind power plants. In addition, the highest daily power production is given for each. With the great majority of wind power plants treated in the statistics, we are dealing with Lykkegaard plants, newly built in the last year. In recent months a series of F. L. S. Aeromotors has also been added.

The wind electricity statistics certainly give a generally spotty picture of generation. The amount of power produced differs very considerably even with completely identical systems. There are various reasons for this. Primarily, of course, the position of the wind power plant and the wind conditions prevailing at its location are decisive. Here it has appeared repeatedly that if the existing conditions are not adequately considered, generation will not reach the expected level (in Denmark, west

* Numbers in margins represent pagination in the original foreign text.

winds prevail). Furthermore, the unfavorable effect of buildings and trees at relatively great distances (over 100 m) is determined differently.

A second important reason for the considerable scattering of power generation is the unequal utilization of the plants. A large portion of the Lykkegaard wind power plants are shut down at night because the relatively small batteries would quickly be charged if the wind increased suddenly, but automatic shutoff is not provided. At low load and high wind velocities, the battery is soon charged even in daily operation, so that any favorable wind conditions which exist cannot be utilized any more. Installation of an appropriately large battery is not practical either, because this would entail very considerable added costs which would significantly increase the cost of power generation. From these conditions there arises the fact that not all the existing wind can be used for power generation. This loss, however, can be limited to the very minimum by matching consumption to the generation. In the Danish plants this has been attempted, as previously shown*, by having the wind power plants normally working in parallel with a producer gas plant which bridges over the calms and provides the necessary current when there is an added energy requirement. Here, the wind power plant takes on the basic load, so that when the minimum velocity is exceeded the generator begins to feed the network through the batteries. In most Danish wind power plants the producer gas engines can no longer be considered as a reserve system because their capacity significantly exceeds that of the wind power plants. In these cases the operation is set up so that the wind power plant serves only to unload the Diesel system. In this manner of operation, naturally, the wind power plants are best utilized, because the existing wind velocities can be utilized less than fully only if the load drops below the existing power supply.

* See No. 15, 5 August 1942, pages 248/249.

A large port of the wind electric plants, however, do not give enough attention to the wind conditions. They work with the producer gas plants most of the time, so that the wind wheels are connected only at relatively great wind speeds. They are not utilized at all for most of the year, with an average wind of 4 - 6 m/s blowing. It has been established that a wind power plant which generates 2,200 kWh in a month, in the manner presented, could have generated three times as much with consideration of the existing wind supply. This fact allows us to conclude that special attention must be devoted to rational operating ways and site location for wind power plants which are to be newly built. Furthermore, it appears reasonable to provide the batteries with an automatic switching system which disconnects the line from the generator after charging is complete.

All in all, though, in spite of the differences in generation data, the wind electricity statistics give good conclusions about the Danish wind power plants. In this respect, Table 1 gives the monthly generation for 22 identical Lykkegaard wind power plants with 18 m vane diameter after November 1940. Exceptionally good and less productive plants have been combined for the table so as to get an appropriate average.

The average generation of the wind power plants studied for the year 1941, some 35,000 kWh (Figure 1), is an appropriate average for the practical operating conditions. It can be used / 391 as a basis for calculating efficiency, under reasonably favorable conditions, in planning. Table 2, however, shows that considerably higher values can be attained with good operating management. The monthly generation of four plants is summarized in this table. These are the plants in Askov, Besser Samso, Kappendrup and Kølstrup. The mean generation from these plants – 50,000 kWh – is plotted for comparison in Figure 1. It is noteworthy here that both curves sink considerably in the summer. This is not

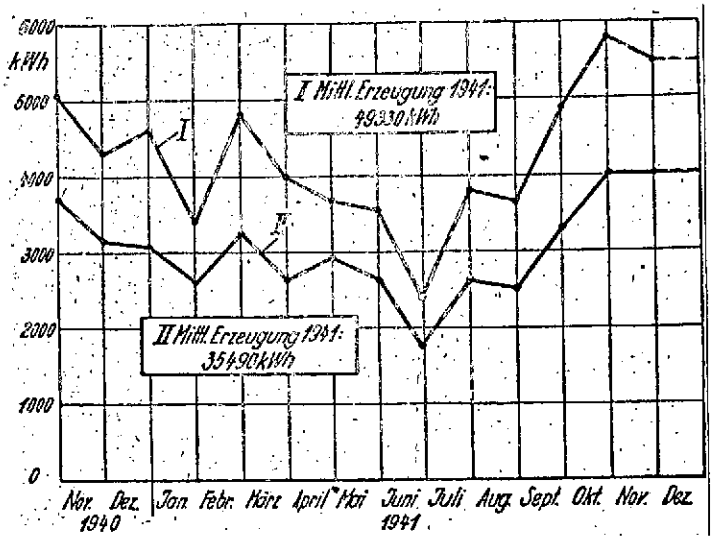

Figure 1. Average generation during the year by Danish wind power plants, 1940/41.

Table 1. MAXIMUM, AVERAGE AND MINIMUM GENERATION FOR 22 LYKKEGAARD WIND POWER PLANTS FOR SOME CHARACTERISTIC MONTHS IN 1940/41.

Month	Generation		
	Minimum kWh	Average kWh	Maximum kWh
1940			
November	1482	3700	5745
1941			
February	0*	2620	4220
April	0*	2640	7521
July	780	1780	2929
November	1411	4010	7002

* Repair and overhaul work.

a serious factor, however, because of the reduced lighting load. On the other hand, we can see a quite considerable generation during the winter months (November to February). Presentation of the average generation mades possible more conclusions about the wind frequency in Denmark. It is apparent, for instance, that sufficiently strong winds for successful operation of wind power plants are present during the months of September to May.

Along with the average monthly generation, we are primarily interested in the daily power generation. Figure 2, therefore, shows the generation of the Kølstrup wind power plant (Figure 3) for three characteristic months. The plant manager, Morten Pedersen, has earned special thanks for the utilization of wind power in Denmark. The extremely fluctuating generation in the windy months of September and January is particularly noticeable. This confirms the practicality of operating producer gas systems and wind power plants in parallel. Only then are the generation peaks assimilated, so that the utilization and efficiency can be improved considerably. Also, the daily production figures give a satisfactory foundation for calculating the battery size. In planning a wind power plant, one will proceed by drawing a parallel to the abscissa at the daily power requirement and then determining the number of kWh lacking. Then one can determine the battery size required. The generation curve also makes it possible to draw conclusions as to whether the excess energy will be enough to charge the battery. As the wind conditions change continuously, it is practical in these considerations to investigate the generation curves for the region in question for several years and to apply a safety factor.

The operating results above refer to Lykkegaard wind power plants. As yet, there is only a little numerical data on the F. L. S. Aeromotors, as these plants have been operating for only a few months. We have, therefore, omitted evaluating in any way

Table 2. MAXIMUM, AVERAGE AND MINIMUM GENERATION OF FOUR LYKKEGAARD WIND POWER PLANTS, 1940/41.

Month	Generation		
	Minimum kWh	Average kWh	Maximum kWh
1940			
November	4630	5070	5745
1941			
February	2878	3400	4205
July	2090	2420	2929
November	4178	5790	7002

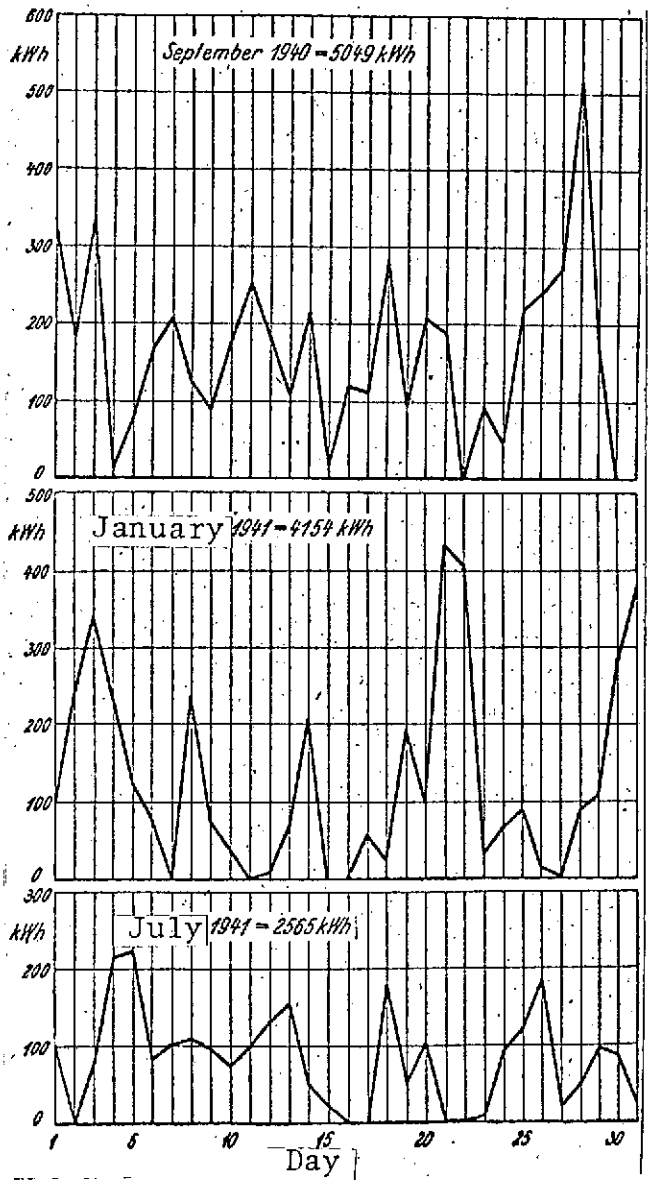

Figure 2. Daily generation of the Kølstrup wind power plant for the months September 1940, January 1941 and July 1941. (Wind wheel diameter 18 m, tower 22 m, power 30 kW at 11 m/s).

the most recent published values in the wind electricity statistics. As already mentioned elsewhere*, the F. L. S. Aeromotor is a well-built wind power plant designed according to modern viewpoints. From the German concept, however, it would still be desirable to simplify the system more and, for example, to make the wind wheel so that automatic starting is possible. Furthermore, the wind power plant will have to start at lower wind speeds and to produce current even at 4 to 5 m/s, with more braking, if necessary, at the high wind speeds which seldom occur. The original dimensioning of the F. L. S. Aeromotors is apparently due primarily to the existing very crude wind measurements. For instance, one reckons on the following wind strengths for Copenhagen and Vamdrup:

Wind Strength m/s	Number of Hours per Year	
	Copenhagen hrs	Vamdrup hrs
< 5	1815	2932
5	731	1572
6	904	1241
7	734	877
8	765	692
9	860	449
10	679	336
>10	2212	661

With 100% utilization of all the wind above 5 m/s, these numbers for Copenhagen would correspond to a potential generation of 235,000 kWh, and 130,000 kWh for Vamdrup. In practice, such values are not attainable for Copenhagen, and we would normally

* See No. 16 from 20 August 1942, page 370.

be able to expect only that the F. L. S. Aeromotors with 17.5 m wind wheel diameter would attain an annual generation of 80,000 to 100,000 kWh under favorable conditions and with further improvement.

Efficiency

Studies of the efficiency of the Danish power plants were made significantly more difficult by the considerable inflation which occured at the beginning of the war. Let us take the Kølstrup wind power plant, for which the conditions are particularly clear, as an example. The plant was built in December, 1939 and has been in continuous operation since then. The / 392 capital expenses were:

Wind power plant with generator and lines but without battery	23,500 dKr
Battery, 300 Ah	14,600 dKr
Total	38,100 dKr

The producer gas system, which is also present in the national electrical works operating with wind power, is not included in this calculation. There were hardly any Kølstrup operating costs during the 18 months of operation because the machinist served both the producer gas system and the wind power system. This was only brief greasing and cleaning work.

With the annual generation of 50,000 kWh which was attained at Kølstrup, and a ten-year amortization, the annual capital costs are

(Amortization, 10 percent and interest, 5 percent)	4,800 dKr
Repairs and lubrication	200 dKr
Total annual costs	5,000 dKr

$$\frac{5\,000\ \text{dKr}}{50\,000\ \text{kWh}} = 0{,}10\ \text{dKr/kWh}.$$

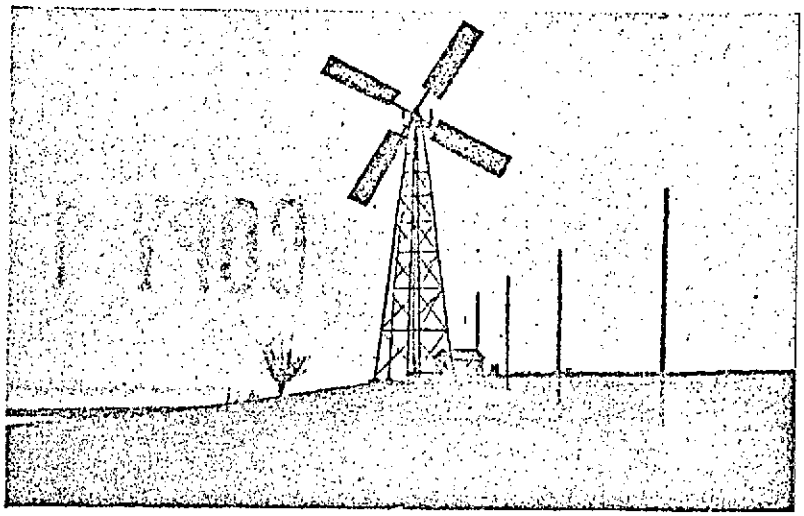

Figure 3. Kølstrup wind power plant (wind wheel diameter 18 m, capacity 30 kW at 11 m/s).

The calculation for this amount is based on the Kølstrup wind power plant. If we insert the inflation which has occurred in the meantime and an average power production according to Table 1 into the calculation, we will arrive at a power cost with the other wind power plants which is never above 20 Øre/kWh. On the contrary, for instance, for Kølstrup the power cost on connection to a high-voltage network is 15 Øre/kWh for heating, 30 Øre/kWh for power and 50 Øre/kWh for light, so that wind operation pays off in all cases, as long as Diesel oil is not on hand.

The efficiency of the Lykkegaard plants can also be determined from the fact that up to some time ago the company provided its wind power plants free and required only a power price of 10 Øre/kWh.

As already emphasized, it is not yet possible to perform an efficiency calculation for the F. L. S. Aeromotors.

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